An Object Detection Method and System

FIELD OF THE INVENTION

This invention is generally in the field of proximity sensing techniques, and relates to a method and system for monitoring a region of interest to detect an object therein.

5 **BACKGROUND OF THE INVENTION**

Proximity sensing systems aimed at object detection in general are well known *per se* and are found in wide use in commercial, police and military applications. Generally, such systems fall into two broad categories of systems: "active" systems based on signal transmission towards an object and detection of

10 signals returned (reflected) from the object, and "passive" systems that do not utilize energy transmission towards a target to be detected (e.g., infrared or heat-seeking systems).

US Patent No. 4,185,192 discloses a passive optical system utilizing two detectors oriented such that their optical axes and cone shaped fields of view

15 intersect, thereby creating an overlapping region between these fields of view. By this, only those signals from the detectors, which are received simultaneously, being thereby indicative of that the detected light comes from the overlapping region, will cause the generation of a switching signal.

Another example of such a passive optical system for determining the

20 presence of an object by utilizing the creation of a scene at the intersection of two optical paths associated with two detectors is disclosed in US Patent No. 4,317,992.

US Patent No. 4,396,945 discloses the technique that can be utilized in either an active or passive system for determining the position and orientation of an object in space. This technique is based on the determination of the intersection of a line with a plane or with another line.

5   Active systems are also disclosed in US Patents Nos. 4,590,410 and 4,724,480. According to the technique of US'410, which is aimed at detecting small objects, multiple light emitters and multiple light detectors are utilized. According to the technique of US'480, a system is composed of at least one projector generating a non-planar light and at least one camera, which are oriented such that the optical axes 10 of the camera(s) and projector(s) intersect. By this, the projector associated with a first object and the region of intersection associated with a second object can be aligned.

SUMMARY OF THE INVENTION

There is a need in the art to facilitate the detection of an object in a region of 15 interest by providing a novel method and system for monitoring a region of interest.

The main idea of the present invention consists of defining a detecting window of a known location containing a region of interest to be monitored so as to detect objects located solely within the detecting window, and prevent monitoring of regions outside the detecting window. This is implemented by transmitting incident 20 radiation towards the region of interest with a certain transmitting angle so as to define a plane of propagation of the incident radiation, and collecting radiation with a solid angle of collection intersecting with this plane. The detecting window is thus a plane-like region of intersection between the angle of collection and the plane of transmission. In order to optimally use the energy and maximize the signal-to-noise 25 ratio (SNR) in detected radiation, the incident radiation is transmitted towards the region of interest with a certain predetermined angular intensity distribution.

It should be understood that the term *"monitoring"* used herein signifies observing or sensing the region of interest either to simply detect the appearance or existence of an object within the detecting window (region of interest), or to enable

imaging of the region of interest. For example, a detector may be of that kind producing generated data indicative of the detected reflections in the form of an indication signal (alarm) indicative of the fact that an object exists in the detecting window. To enable the imaging of an object located within the detecting window, an appropriate detector (i.e., having a sensing surface in the form of one- or two-dimensional array of pixels) and an image processing technique should be used.

There is thus provided, according to one aspect of the present invention, a method for monitoring a region of interest, the method comprising the steps of:

(a) transmitting incident radiation towards the region of interest with a certain transmitting angle to define a plane of propagation of the incident radiation, and with a predetermined angular intensity distribution of the incident radiation, the region of interest being located within said plane;

(b) collecting reflections of the incident radiation with at least one solid angle of collection intersecting with said plane, a region of intersection being a detecting window of a predetermined geometry containing at least a portion of said region of interest;

(c) detecting the collected radiation coming from within said detecting window and generating output signals indicative thereof.

Preferably, to provide the predetermined angular intensity distribution of the incident radiation, a transmitter unit comprises a specifically designed beam-shaping element.

Preferably, in order to increase the quality of detection, the sensitivity distribution of a receiver unit within the sensing surface of a detector is adjusted so as to provide substantially uniform output of the receiver unit for collected radiation components coming from different locations within the detecting window. Additionally, the sensing surface of the receiver unit can be divided into a plurality of spatially separated sensing regions, each for collecting a corresponding one of the solid angle segments of the collection angle of the receiver unit.

According to another aspect of the present invention, there is provided a system for monitoring a region of interest, the system comprising:

(One) a transmitter unit operable to transmit incident radiation with a certain transmitting angle defining a plane of propagation of the incident radiation, and with a predetermined angular intensity distribution of the incident radiation, said region of interest being located within said plane; and

(Two) at least one receiver unit oriented and operable to collect reflections of the incident radiation with at least one certain solid angle of collection intersecting with said plane, a region of intersection being a detecting window of a predetermined geometry containing at least a portion of said region of interest, to detect the collected radiation coming from within said detecting window, and generate data indicative thereof.

Preferably, in order to prevent stray light (particularly, solar radiation) from reaching the receiver unit, and prevent the reflection of the incident radiation from the ground, the receiver and transmitter units are oriented such that the field of view of the receiver, while being directed towards the detecting window, extends downwards from the horizon, and the incident radiation, while propagating towards the detecting window, is directed upwards from the horizon. For the same purpose, namely, to prevent the stray light from being detected, an additional receiver unit can be used to collect the reflections of the incident radiation coming from within the detecting window, but with a different collection angle. For example, the two receivers are oriented such that their collection angles are symmetrical with respect to the detecting window plane. This arrangement prevents the direct solar radiation from being detected simultaneously by the two receiver units.

Generally, more than one receiver units may be provided being associated with the same transmitter unit and being operable for receiving radiation components propagating with a corresponding one of solid angle segments of said solid angle of collection. More than one transmitter units may be provided associated with a

corresponding number of the receiver units, thereby monitoring the corresponding number of portions (detecting windows) of the region of interest.

The transmitter unit comprises a radiation source (preferably a laser diode) generating the incident radiation of a predetermined spectral range, a collimator, and a beam-shaping element providing the desired angular intensity distribution of the incident radiation. The beam-shaping element is of a refractive type, and is composed of one or more refractive blocks. Each of the refractive blocks has a first active surface facing the radiation source, a second active surface and an active medium enclosed between the first and second surfaces, and is formed by an array of facets. The orientation of a surface region of the first active surface defined by the facet with respect to the second active surface and a length of this surface region are defined by the angular intensity distribution of the incident radiation to be created by the radiation propagation through this specific facet.

Thus, according to yet another aspect of the present invention, there is provided a beam-shaping element for use in a transmitter unit for transmitting radiation with a predetermined angular intensity distribution, wherein

- the beam-shaping element comprises at least one refractive block having a first active surface for facing a radiation source of the transmitter unit, a second active surface and an active medium enclosed therebetween;

- the first active surface of said at least one refractive block is formed by an array of facets, orientation of a surface region of the first active surface defined by each of the facets with respect to the second active surface and a length of said surface region being defined by the predetermined angular intensity distribution, $I(\theta)$, of the transmitted radiation to be produced by radiation propagation through said at least one refractive block, θ being a steering angle created by the facet of the refractive block.

Preferably, the beam-shaping element is also designed so as to be very robust to linear intensity variation of the emitted radiation at the entrance of the beam-shaping element (at the first active surface). To this end, the array of facets is

composed of two sets, which are symmetrically identical with respect to the central axis of the refractive block.

The receiver unit comprises a spectral filter preventing the detection of radiation outside said predetermined frequency spectral range, a radiation collecting assembly and a detector. A sensing surface of the detector has a predetermined geometry selected in accordance with the geometry of the detecting window (region of interest). The detector is implemented with a specifically constructed variable sensitivity filter, such that the output of the detector is substantially uniform for the collected reflections coming from different locations in the detecting window. This filter also reduces the overall stray light (background radiation) and back-scattered radiation from particles that may occasionally exist in the detecting window and scatter light towards the receiver unit.

Thus, according to yet another aspect of the present invention, there is provided a detector for use in a system for monitoring a region of interest, the detector comprising a radiation collecting assembly, and a sensing surface for receiving collected radiation and generating output representative thereof, wherein the sensing surface has a desirably variable sensitivity distribution such that the output signals corresponding to the collected radiation components coming from different locations within said region of interest are substantially equal.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 is a schematic illustration of the main components of a system according to the invention;

Fig. 2 illustrates the construction of a transmitter unit of the system of Fig. 1;

Figs. 3a to 3c more specifically illustrate the features of a beam-shaping element of the transmitter unit of Fig. 2;

Fig. 4 illustrates the construction of a receiver unit of the system of Fig. 1; and

Fig. 5 more specifically illustrates the geometry of a sensing surface of the receiver unit given in an enlarged scale.

5 **DETAILED DESCRIPTION OF THE INVENTION**

Referring to Fig. 1, there is illustrated a system **10** according to the invention for monitoring a region of interest **12**, namely, for detecting the appearance or existence of an object within this region (detecting window). The system **10** comprises such main constructional parts as a transmitter unit **14** for generating

10 incident radiation (light) and transmitting it towards the region of interest **12** (detecting window), and a receiver **16** unit for receiving reflections of the incident radiation coming from the region of interest **12** and generating data indicative thereof.

The transmitter unit **14** generates an incident light beam L_{inc} of a predetermined spectral range and transmits it with a certain acute angle of

15 propagation θ and certain angular intensity distribution of the incident light. The incident light beam has a substantially plane shape (the so-called "sheet of light"), and the region of interest **12** is located in this plane **P**. The receiver unit **16** collects light L_{col} (of the predetermined spectral range) with a solid angle of collection ϕ.

The detecting window **12** presents a region of intersection between the plane

20 **P** (defined by the transmitter unit **14**) and the solid angle of light collection ϕ (defined by the receiver unit **16**). In other words, the detecting window **12** is a region cut by the solid angle of light collection ϕ from the plane **P**. In the present example, the solid angle of collection ϕ has a rectangular cross-section, thereby defining a rectangular shape of the detecting window **12**.

25 It should be understood that what the receiver unit **16** actually receives are reflections of the incident light produced within a region defined by the detecting window **12** (i.e., light reflected from an object located within the window **12**). The system **10** is thus capable of monitoring the detecting window containing the region

of interest, i.e., detecting, and possibly also imaging, objects located within the detecting window 12, while not detecting any object located outside this window.

With regard to the preferred relative position of the transmitter and receiver units, the following should be noted. The receiver unit 16 is oriented such that its field of view, while being directed towards the detecting window 12, extends downwards from the horizon. The transmitter unit 14 is oriented such that the incident radiation, while propagating towards the detecting window 12, is directed upwards from the horizon.

The above positioning of the transmitter and receiver units 14 and 16 is associated with the following. On the one hand, when stray light (in particular, the solar radiation) directly reaches the sensing surface of a detector, it causes the saturation of the detector. On the other hand, the reflections of incident laser radiation from the ground can reach the sensing surface of a detector, thereby causing a false alarm thereof. By locating the transmitter and receiver units in the above-described manner, the solar radiation is prevented from reaching the detector (irrespective of the current location of the Sun), and the incident radiation is prevented from reaching the ground.

It should be noted, although not specifically shown, that, in order to prevent the stray light from being detected, the system may comprise an additional receiver unit constructed similar to the receiver unit 16, but oriented to collect the reflections of the incident radiation coming from within the detecting window 12 symmetrical to that of the unit 16 with respect to the detecting window plane. This arrangement prevents the direct solar radiation from being detected simultaneously by the two receiver units.

Generally, the system may comprise more than one receiver unit associated with the same transmitter and operable together to collect the reflections of the incident radiation from the detecting window with the solid angle of light collection ϕ. In this case, each of the receiver units collects a light component propagating with a corresponding one of the angular segments of the entire solid angle of light collection ϕ.

It should also be noted that, in order to monitor the entire region of interest, the system may comprise more than one transmitter unit, each being associated with one or more receiver unit. In this case, each transmitter-receiver arrangement is associated with a corresponding one of the detecting windows that cover together the entire region of interest. In other words, the entire region of interest can be monitored by dividing it into a number of detecting windows, and detecting the reflections coming therefrom by the corresponding number of the transmitter-receiver arrangements.

Fig. 2 illustrates the main constructional elements of the transmitter unit **14**. The transmitter unit **14** is composed of a laser diode (radiation source) **18** operating with the predetermined spectral range, an aspheric collimating lens **20**, and a beam-shaping element **22**. A light beam B_1 emitted by the laser diode **18** is collimated by the lens **20**, and the passage of collimated light B_2 through the element **22** produces the incident sheet of light L_{inc}. It should be understood that the light propagation is shown here schematically, in order to simplify illustration.

For the purposes of the present invention, the beam-shaping element **22** is of a refractive type, having two active surfaces **22a** and **22b** enclosing an active medium **M** with the refraction index n therebetween. The element **22** is formed of one or more blocks, five such blocks, generally at **23**, being shown in the present example. By using two active surfaces, the maximum angle of propagation of the incident radiation produced by the beam-shaping element can be increased. The beam-shaping element **22** is designed using a specific algorithm, so as to provide desired angular intensity distribution of the incident light. Additionally, the beam-shaping element is designed so as to be very robust to laser intensity variations. As for the aspherical collimating lens **20**, its design is optimized for actual laser junction to achieve maximum collimation capability.

Turning now to Figs. 3a-3c, there are illustrated the main principles underlying the design of the beam-shaping element **22**. In Fig. 3a, one block **23** of the element **22** is exemplified. The block **23** is composed of $2N$ facets formed by two sets of facets (point-like locations) **F** and **F'**, each set consisting of N facets, and

the sets being identically symmetrical with respect to the central axis **CA** of the block **23**. Thus, the set **F** is composed of N facets F_i (where i=1, ..., N), and the identically symmetrical set **F'** is composed of N facets F'_i (where i=N+1, ..., 2N).

Fig. 3b illustrates the light propagation through one of the facets F_i. The
5 emitted collimated light beam B_2 impinges onto the surface region **22a** defined by the facet F_i at an angle φ_i, successively passes through the medium **M** and the interface defined by the second active surface **22b** of the facet F_i, and ensues from the facet F_i as the light component $L^{(i)}_{inc}$ of the output incident light L_{inc} with the specific angle of propagation θ_i (i.e., the angular segment of the acute angle of propagation θ of the
10 incident light). The projection d_i of the surface **22a** onto the plane of the other active surface **22b** that actually defines the length of the facet F_i, is determined in accordance with the light intensity $I(\theta_i)$ which should be produced by the light propagation through this facet.

Considering the entire block **23** composed of $2N$ facets F_i, each angle φ_i will
15 have its corresponding angle θ_i, and, accordingly, the angular intensity distribution $I(\theta)$ of the incident light is formed by the intensities of the $2N$ light components passed through the $2N$ facets of the block **23**, i.e., $I(\theta_i)$.

Fig. 3c illustrates the angular intensity distribution as produced by the entire block **23** formed by symmetrically-identical facet-sets F_i and F'_i.

20 Thus, in order to provide certain desired angular intensity distribution of the incident light, the facets of the block of the beam-shaping element should be designed accordingly. The algorithm underlying the above design of the block of the beam-shaping element **22** consists of the following. The desired output angular intensity distribution of block **23**, $I(\theta)$, is quantized into a discrete set of angles θ_i,
25 each angle defining the tangential of the first active surface **22a** which can be found by solving the following transcendental equation:

$$\theta_i = \arcsin[n\sin(\varphi_i - \arcsin(\frac{\sin\varphi_i}{n}))] \quad (1)$$

wherein θ_i is the specific angle of propagation of light ensuing from the facet for
30 which the tangential φ_i must be found.

Taking into account that the length d_i of the corresponding facet F_i for each angle θ_i is proportional to the relative output intensity at that angle $I(\theta_i)$, each facet F_i of the block **23** is calculated. By this, the desired angular intensity distribution of light ensuing from the beam-shaping element can be obtained.

5   In order to make the angular intensity distribution of the transmitter unit substantially independent of the linear non-uniformity of the laser diode radiation, the two sets **F** and **F'** of successive facets (i.e., F_1, F_2, ..., F_N, and F_{N+1}, F_{N+2}, ..., F_{2N}) are identically symmetrical with respect to the central axis **CA** of the block **23**. This is implemented by rotating each facet in one set the angle of 180° with respect to its

10   corresponding facet in the other set (i.e., F_1 and F_{2N}, F_2 and F_{2N-1}, ..., F_N and F_{N+1}).

The above technique dramatically increases the robustness of the element **22** to the possible linear intensity variation in the laser **18**, thereby providing substantially non-sensitivity of the incident light produced by the transmitter unit to any linear intensity variation of light emitted by the laser at the entrance to the beam-

15   shaping element (i.e., at the surface **22a**).

It should be noted that in order to further increase the robustness of the beam-shaping element to intensity variations, the entire arrangement of *2N* facets (block **23**) can be scaled and periodically repeated. The scaling factor and number of periods solely depends on the quality of the laser **18**: the less the uniformity of light

20   distribution emitted by the laser, the lower scale and greater number of periods should be used.

Fig. 4 illustrates the main components of the receiver unit **16**, which is of a pseudo-imaging kind. The receiver unit **16** comprises an optical system **30** (constituting a radiation collecting assembly), a detector **32**, and a protective window

25   **34** accommodated in front of the optical system **30** (with respect to the direction of propagation of light impinging onto the receiver unit), all being accommodated in a metal housing **36**. The optical system **30** is composed of a lens assembly **38** and a laser wavelength matched spectral filter **40** accommodated in front of the lens assembly **38**. The lens assembly **38** includes a first aspherical lens **38a** and a second

30   spherical lens **38b** (with respect to a direction of propagation of the collected

radiation through the receiver unit), which are mounted adjacent to each other and define a common optical axis **OA** of light propagation within the receiver unit towards a sensing surface **32a** of the detector **32**.

The receiver unit **16**, having the above design of the optical system **30**, is

5   capable of providing a very large field of view and depth of focus, to meet the requirements of the imaging system. The optical system **30** is capable of creating an image of the detecting window (**12** in Fig. 1) on the sensing surface **32a**. Angular imaging resolution may vary over the field of view in order to provide the uniform spatial resolution of the detecting window.

10   The sensing surface **32a** of the detector **32** is specifically designed so as to provide a desired sensitivity distribution within the sensing surface **32a** of the detector resulting in substantially uniform output from different points on the sensing surface. This is associated with the fact that the design of the detecting window (i.e., its orientation with respect to the optical axis **OA**) may result in that the detected

15   light components coming from locations (points) in the detecting window differently distanced from the plane of the sensing surface **32a**, will have different intensities. Hence, to provide uniform output signals from the detector **32**, a specifically constructed variable sensitivity filter should be implemented in the detector **32**.

As shown in Fig. 5, illustrating the sensing surface **32a** in an enlarged scale,

20   the shape of the sensing surface **32a** is selected in accordance with the shape of the detecting window **12** by projecting the contours of the detecting window **12** onto the sensing surface **32a** through the optical system **30** of the receiver unit **16**. In the present example of the rectangular-shaped detecting window **12**, the projection of the points P_1-P_4 results in points $P_{1'}$-$P_{4'}$, forming the trapezoid shape of the sensing

25   surface **32a**.

It should be noted, although not specifically shown that, in order to increase the depth of focus, the detector **32** should be oriented such that its sensing surface **32a** is not perpendicular to the optical axis **OA** of the optical system **30**, but rather appropriately inclined thereto. The angle of inclination can be determined by any

30   suitable technique, for example, by the least square method, which is known *per se*.

To enable the light detection with substantially uniform output of the detector, the inventors have developed an iteraction algorithm for the calculation of the sensitivity filter function to provide desirably variable sensitivity of the detector. This algorithm consists of the following:

It is known that, in the first approximation, the transmission function of the filter $T_1(x,y)$ can be calculated based on the following formula:

$$T_1(x,y) = c \cdot \frac{R_1 \cdot R_2^2}{I(\theta(\vec{R_1}))} \qquad (2)$$

wherein x and y are the coordinates in the filter plane, i.e., the sensing surface **32a**; $\vec{R_1}$ is a vector connecting the transmitter unit **14** with a specific point in the detecting window **12**; $I(\theta(\vec{R_1}))$ is the intensity of a signal generated by the transmitter unit **14** and transmitted in the $\vec{R_1}$ direction; $\vec{R_2}$ is a vector connecting the specific point in the detecting window **12** with the receiver unit **16**; and c is a normalization factor chosen to achieve maximum overall transparency.

The above equation (2), however, does not take into account the actual point spread function (PSF) of the system, which should be taken into account when dealing with the performance of a real system. In this case (i.e., considering the PSF), the intensity distribution I_1 of the detector output reads:

$$I_1(x_d, y_d) = \iint_{\substack{overthe \\ detector \\ plane}} T_1(x,y)P(x - x_d, y - y_d)\,dxdy \qquad (3)$$

wherein $P(x{-}x_d, y{-}y_d)$ is the actual PSF of the optics of the receiver unit, (x_d, y_d) being the coordinates of a current location in the detector plane (sensing surface **32a**).

Thus, for each point in the detecting window **12**, the corresponding PSF on the detector plane **32a** can be found by using the known available ray-tracing code. In the present example, the OSLO SIX software product commercially available from

Sinclair Optics Inc., USA was used. Other known codes, such as Zemax or Code V, can be used. Then, this PSF is multiplied by $T_1(x,y)$ and numerically integrated over the entire detector plane, thereby producing an actual signal on the detector (equation (3) above).

5   This process is repeated for an appropriate grid of points in the detecting window **12**, thereby producing the sensitivity map on the detector plane **32a**. If PSF were an ideal impulse response, namely delta function, the map of sensitivity would be uniform. In practice, however, owing to the fact that the actual PSF is blurred by real optical system, a uniform sensitivity map cannot be obtained.

10   In order to achieve the uniform output of the detector, the desirably variable sensitivity map of the detector should be provided. To this end, the iteration algorithm is based on correcting (varying) the transmission function $T_1(x,y)$ by normalizing it with respect to the calculated sensitivity map, thereby producing a new transmission function $T_2(x,y)$:

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$$T_2(x_d, y_d) = \frac{T_1(x_d, y_d)}{I_1(x_d, y_d)} \qquad (4)$$

This process is repeated until appropriate uniformity of the detector output is obtained. More specifically, for k-th level of iteration of the transmission function 20 $T_k(x,y)$ (i.e., k-th step of the optimization procedure), the corresponding value of the intensity function $I_k(x,y)$ is calculated as described above (equation (3)), and, accordingly, the next iteration level $T_{k+1}(x,y)$ in the iteration procedure is found. The iteration procedure continues until the required uniformity of the detector output $I(x,y)$ is achieved.

25   The simulations have shown that the iteration procedure converges very fast (about 5 iterations), producing quite uniform output from the detector (better than 5% P-V).

The above variable transmission (sensitivity) of the detector can be implemented by appropriately patterning the sensing surface **32a** of the detector in

different ways. For example, the pattern may be fabricated in a separate, specifically coated glass plate and placed on the sensing surface. Alternatively, the correspondent transmission filter (pattern) or the different sensitivity can be implemented directly on the detector by means of ion implantation of the detector's sensing surface (e.g., Si-B).

Those skilled in the art will readily appreciate that various modifications and changes can be applied to the preferred embodiment of the invention as hereinbefore exemplified without departing from its scope defined in and by the appended claims.